J Orofac Orthop (2017) 78:330–337
DOI 10.1007/s00056-017-0089-x

ORIGINAL ARTICLE

Thermal imaging of the pulp during residual adhesive removal
Thermographie in der Pulpa während der Entfernung von Adhäsivresten

Gökmen Kurt[1] · Nisa Gül[2] · Özgür Er[3] · Gülşen Çakmak[2] · Emre Bendeş[4] · Veysel Aslantaş[4]

Published online: 13 March 2017

Abstract
Objective The aim of this study was to evaluate the temperature changes of the pulpal area during different adhesive clean-up procedures.
Materials and methods A total of 80 freshly extracted adult maxillary premolar teeth were divided into four groups. Adhesive clean-up was performed with 6- and 12-fluted tungsten carbide burs (TCB) using low- and high-speed handpieces with air or water cooling after bracket debonding. The temperature changes and cool down times were evaluated with a thermal camera. Paired *t* test, analysis of variance (ANOVA), and Student–Newman–Keuls multiple comparison analysis were used for statistical analysis of the data.
Results All experimental groups, except the water cooling group, showed a significant temperature rise ($p < 0.001$) after residual adhesive removal. Only the 6-fluted TCB group with air cooling using a high-speed handpiece exceeded the critical 5.5 °C threshold value (5.91 ± 0.89 °C); this group also exhibited the longest cool down time to initial temperature (71.95 ± 13.68 s). The smallest temperature rise (0.48 ± 0.90 °C) and shortest cooling time value (11.90 ± 5.3 s) were measured in the 6-fluted TCB group with water cooling using a high-speed handpiece.
Conclusion Appropriate cooling procedures and fine tungsten carbide burs should be used during the removal of remnant adhesives after bracket debonding in order to prevent adverse pulpal reactions.

Keywords Thermal imaging · Pulp · Adhesive removal · Temperature rise · Orthodontic brackets

Zusammenfassung
Zielsetzung Ziel der Studie war die Evaluierung von Temperaturveränderungen im Bereich der Pulpa während unterschiedlicher Verfahren für die Entfernung von Adhäsivresten.
Material und Methoden 80 frisch extrahierte Oberkieferprämolaren von Erwachsenen wurden in 4 Gruppen eingeteilt. Nach dem Bracket-Debonding wurde das Adhäsiv mittels Hartmetallfinierern (tungsten carbide burs, TCB) mit 6 bzw. 12 Schneiden an Hoch- bzw. Niedergeschwindigkeitshandstücken und bei Luft- oder Wasserkühlung entfernt. Temperaturänderungen und Abkühlzeiten wurden mit einer Thermokamera evaluiert. Zur statistischen Datenanalyse wurden gepaarter t-Test, ANOVA (analysis of variance) und der Student–Newman–Keuls-Test verwendet.
Ergebnisse Mit Ausnahme der Versuchsgruppe, in der Wasserkühlung verwendet wurde, zeigte sich in allen Gruppen ein signifikanter Temperaturanstieg ($p < 0{,}001$) nach Entfernung der Adhäsivreste. Nur in einer Gruppe (6-Schneiden-TCB, Luftkühlung, Hochgeschwindigkeitshandstück) wurde mit 5,91 ± 0,89 °C der kritische 5,5 °C-Schwellenwert überschritten, in dieser Gruppe waren auch die Zeiten bis zur Abkühlung auf die Ausgangstemperatur am längsten (71,95 ± 13,68 s). Der geringste Temperaturanstieg

✉ Gökmen Kurt
gokmenkurt@hotmail.com

[1] Department of Orthodontics, Faculty of Dentistry, Istanbul Yeni Yuzyil University, Istanbul, Turkey

[2] Department of Orthodontics, Faculty of Dentistry, Erciyes University, Kayseri, Turkey

[3] Department of Endodontics, Faculty of Dentistry, Trakya University, Edirne, Turkey

[4] Department of Computer Engineering, Faculty of Engineering, Erciyes University, Kayseri, Turkey

(0,48 ± 0,90 °C) und die schnellste Abkühlung (11,90 ± 5,3 s) zeigten sich in der Versuchsgruppe mit 6-TCB, Wasserkühlung und Hochgeschwindigkeitshandstück.
Schlussfolgerung Während der Entfernung von Adhäsivresten nach Bracket-Debonding sind zur Prävention unerwünschter Reaktionen im Bereich der Pulpa geeignete Kühlverfahren und feine Hartmetallfinierer einzusetzen.

Schlüsselwörter Thermographie · Pulpa · Adhäsiventfernung · Temperaturanstieg · Kieferorthopädische Brackets

Introduction

Direct bonding of orthodontic brackets provided many benefits including better hygiene, reduced caries risk, better esthetics and performance, low costs, more accurate bracket positioning, and decreased chair time [4]. The residual adhesive after debonding of the orthodontic brackets must be removed to avoid accumulation of plaque and surface staining. Removal of the adhesive resins from tooth surfaces should be performed without iatrogenic damage such as rough enamel surfaces, gingival irritation, cracks, and pulp injury [4].

Various types of mechanical adhesive removal methods have been described in the literature, including adhesive removal pliers, tungsten carbide and diamond burs of low and high-speed handpieces, abrasive discs, ultrasonic units, air abrasion techniques, and laser applications [4, 17]. Tungsten carbide burs (TCB) were reported as the most efficient method for resin removal [15]. Zachrisson and Årtun evaluated the quality of the enamel surface after debonding of brackets and tested thin diamond burs, coarse strips, medium and fine sandpaper, green rubber tips, and tungsten carbide burs [21]. Low-speed TCB application showed the best results among tested procedures with less enamel loss and superior accessibility into anatomical grooves as other areas [21]. On the other hand, Zarrinia et al. [22] recommended the use of high-speed TCB for removal of remnant resin.

Pulpal temperature rise after various dental applications such as cavity preparation, composite polymerization, curing lights, and bleaching have been investigated in the literature [13], but the extent of temperature rise that causes actual damage to pulpal tissues is still questionable [10]. In 1965, Zach and Cohen studied pulpal damage due to heat in primates, and found that a 5.5 °C temperature rise in pulp led to irreversible damage in 15% of Macaca rhesus monkeys, an 11 °C increase caused irreversible pulp alterations in 60% of the animals, and a 16.5 °C increase resulted in irreversible necrotic response of pulp tissue for all animals [20]. Thus, a 5.5 °C temperature rise of the pulp chamber has been used as a threshold value for studies evaluating the temperature changes of the pulp with different dental procedures.

A few studies have evaluated the temperature changes during removal of residual adhesives after debonding of orthodontic brackets [7, 18], and all these studies used thermocouple wires for measuring the thermal changes in the pulpal chamber. Some of the heat reaching the pulpal wall can be lost because of the fluid or semifluid conducting medium used by the thermocouple wires. The temperature changes measured with the thermocouple technique is also influenced by the distance between the tip of the thermocouple wire and the pulpal wall [5]. Thermal image recording systems can accurately calculate the temperature changes of the entire pulp chamber during adhesive removal with rotary instruments by measuring the maximum temperature rise in an area rather than a contact point, as in thermocouple wires. Another advantage of using thermal imaging is that information about the time required for the pulpal chamber to cool (cooling duration) to the initial temperature value can be obtained. While few studies have investigated the thermal effects of different remnant composite removal applications [7, 18], there are no studies in the literature that show temperature changes and the cooling duration of the pulp chamber during removal of the residual adhesive from the tooth surface with thermal imaging. Therefore, the aim of this study was to evaluate the temperature changes during different adhesive clean-up procedures using tungsten carbide burs with thermal imaging.

Materials and methods

Sample preparation

A power analysis was completed by G*Power Ver 3.1.9.2 (Franz Faul, Universität Kiel, Germany) software. Based on the 1:1 ratio between groups, a sample size of 20 specimens in each group would give more than 90% power to detect significant differences at a significance level of $\alpha = 0.05$. A total of 80 freshly extracted, non-carious adult human permanent upper first premolar teeth with intact enamel were used for this study. The homogeneity of shape, size, and pulpal chamber dimensions of the teeth were evaluated on digital periapical radiographs taken from a 5 cm fixed focal image distance with commercial software (Adobe Photoshop CS3, Adobe Systems Inc., San Francisco, CA, USA). After radiographic evaluation, teeth with similar hard tissue thickness and similar distance of pulp to enamel surface were used; teeth with abnormally large or small pulp chambers were excluded from the study.

Teeth were stored in 0.1% thymol solution that was changed weekly to prevent the proliferation of bacteria and fungi. The teeth were separated into two parts as buccal and lingual halves. The pulpal chambers were cleaned of remnant pulpal tissues with a spoon excavator and with NaOCl application for one minute. Then, pulp chambers of teeth were rinsed with distilled water and air dried. Samples were embedded vertically in autopolymerizing acrylic resin blocks (Meliodent, Heraeus Kulzer, Hanau, Germany), approximately 2–3 mm below the cementoenamel junction (Fig. 1a). Vertical acrylic walls around the surface of teeth were added to the sample blocks (Fig. 1b) to protect the camera lens from water contact during water cooling. The buccal surfaces of teeth were polished with nonfluoridated pumice using rubber prophylactic cups at low speed for 10 s, cleaned with water for at least 30 s, and then dried with oil-free air.

Bonding procedure

Teeth were randomly divided into four groups of 20 teeth each. The buccal surfaces of samples were etched with 37% phosphoric acid gel (Prime Dental Products, Chicago, IL, USA) for 30 s, rinsed with a water/air spray combination for 30 s, and dried until a characteristic frosty white etched area was observed. On the etched enamel, a thin, uniform layer of sealant (Transbond XT light cure adhesive primer, 3M Unitek, Monrovia, CA, USA) was applied and cured for 10 s with LED light (Valo ortho cordless curing light, South Jordan, UT, USA). Upper first premolar stainless steel brackets (American Orthodontics, 0.018 Roth Mini/Master Series, Sheboygan, WI, USA) were used. A thin coat of isolating solution (Isolant C.M.S., Dentsply, Vic, Australia) was applied on the metal bracket base to ensure all adhesive material remained on the tooth surface instead of bracket base, and drying of the separator was awaited before applying the composite. Transbond XT adhesive composite (3M Unitek, Monrovia, CA, USA) was used for bonding. Brackets were placed on the bonding surface by hand and fully seated into position using an intraoral gauge to deliver a standardized pressure of 250 grams for 5 s for obtaining uniform composite thickness between the bracket bases and the teeth in all samples. Excess adhesive was removed with a sharp excavator. Curing was performed with LED light (Valo ortho cordless curing light, South Jordan, UT, USA) in standard mode with a 10 s exposure time. After curing, all samples were stored in water for 24 h.

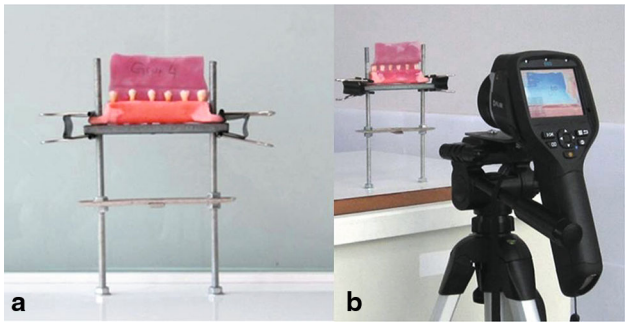

Fig. 1 **a** Preparation of the sample teeth in acrylic blocks for adhesive removal. **b** Thermal imaging of the sample teeth was taken at a distance of 15 cm
Abb. 1 **a** Einbettung der Zähne in Acrylblöcken zur Entfernung des Adhäsivs. **b** Thermographie der Zähne, Messabstand 15 cm

Debonding procedure

Brackets were removed with orthodontic pliers by gently squeezing the bracket wings. Tungsten carbide burs were used for removing of adhesive remnants with four different procedures (Table 1; Figs. 2 and 3). The clean-up procedure was checked under the operatory lamp with the naked eye and was finished when the enamel surface was smooth and free of composite. An air cooling aperture having a 0.7 mm diameter with 32–38 psi (2.20–2.60 bar) and a water cooling aperture having a 24 ± 2 °C water temperature with a water amount of 50 cm^3/min were used for cooling during removal of the adhesive remnants from the samples with rotary instruments.

Tab. 1 Definition of the study groups
Tab. 1 Definitionen der Untersuchungsgruppen

Groups	*n*	Type of handpiece	Type of bur	Type of coolant
Group I	20	Contra-angle low speed (below 15,000 rpm)	6-fluted tungsten carbide (Meisinger No: HM21R-RA 1158, Neuss, Germany)	Air cooling
Group II	20	High speed (290,000 rpm)	12-fluted tungsten carbide (Meisinger No: HM244K-FG 1158, Neuss, Germany)	Air cooling
Group III	20	High speed (290,000 rpm)	6-fluted tungsten carbide (Meisinger No: HM21R-FG 1158, Neuss, Germany)	Water cooling
Group IV	20	High speed (290,000 rpm)	6-fluted tungsten carbide (Meisinger No: HM21R-FG 1158, Neuss, Germany)	Air cooling

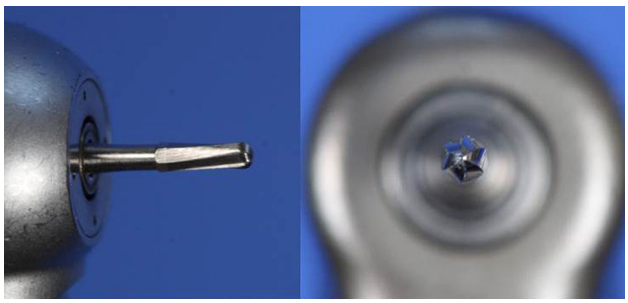

Fig. 2 Example of a 6-fluted tungsten carbide bur
Abb. 2 Beispiel eines Hartmetallfinierers mit 6 Schneiden (6-fluted tungsten carbide bur)

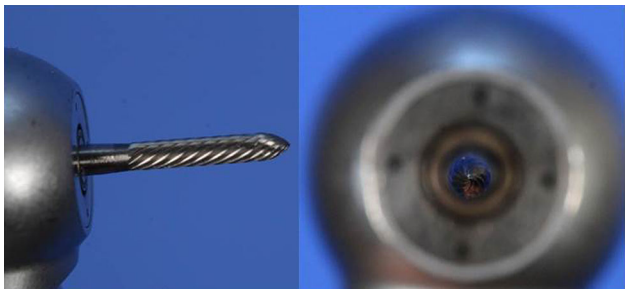

Fig. 3 Example of a 12-fluted tungsten carbide bur
Abb. 3 Beispiel eines Hartmetallfinierers mit 12 Schneiden (12-fluted tungsten carbide bur)

Thermal measurement

FLIR E60 thermal imaging camera (Extech Instruments Corporation, Waltham, MA, USA) and its own software package were used to measure the temperature changes during different clean-up procedures (Fig. 1b). The acrylic sample blocks were perpendicularly fixed on a specially designed board (Fig. 1a), and the camera was placed at a 15 cm distance to the pulpal site of the samples to standardize the thermal measurements and camera records for all specimens (Fig. 1b) [9]. Resolution of the camera was 320 × 240 pixels, field of view was 25 × 19°, and the temperature window was adjusted to a minimum of 20 °C and a maximum of 40 °C. All measurements and records were performed in a special room with controlled environmental conditions (ambient temperature = 24 ± 0.9 °C; relative humidity = 44 ± 5%; air flow = <0.5 m/s; Fig. 4). For obtaining the best image, the focus of the objective was checked manually.

Thermal camera recording was started 2 s before clean-up. For all specimens, temperature changes during adhesive removal and the time for returning to the initial values were recorded (Fig. 5). Temperature changes during clean-up for each tooth were calculated by subtracting the initial temperature from the highest temperature value. The critical temperature threshold value was calculated by adding

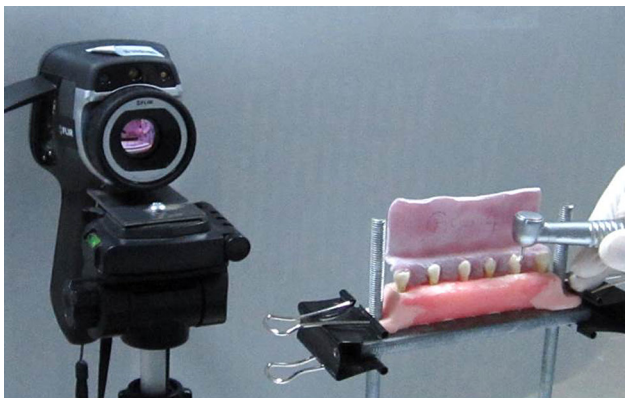

Fig. 4 Setup to record temperature changes during residual adhesive removal
Abb. 4 Versuchsdesign zur Aufzeichnung der Temperaturänderungen während der Entfernung von Adhäsivresten

5.5 °C to the initial temperature. Time needed for cooling to the critical temperature threshold value (critical cooling time) and to initial temperature changes (cooling time) were also calculated.

Statistical analysis

The Shapiro–Wilk test was used to evaluate the distribution of the parameters. All parameters were found normally distributed, so the temperature and time changes were analyzed with parametric tests. The initial and final means and standard deviations of time and temperature values were calculated and analyzed with the paired *t* test. Comparisons of all parameters between groups were achieved with the analysis of variance (ANOVA) test and Student–Newman–Keuls method using SPSS (IBM Statistical Package for social Sciences, Version 20.0 SPSS, Chicago, IL, USA) at the $p < 0.05$ significance level.

Results

The initial and final means and standard deviations of the temperature changes in the experimental groups are presented in Table 2. All clean-up procedures resulted in significant changes in the initial temperature of the samples ($p < 0.001$), except Group III, in which water was utilized for cooling. Group IV with air cooling in a high-speed handpiece exhibited the highest temperature changes among groups (5.91 ± 0.89 °C) and the lowest temperature rise was found in Group III (0.48 ± 0.90 °C) with water cooling in a high-speed handpiece (Table 2).

The high-speed handpiece groups with air cooling showed the longest cool down time (CT) to initial temperature: 71.95 ± 13.68 s for Group IV using a 6-fluted tungsten carbide bur and 51.95 ± 12.50 s for Group II

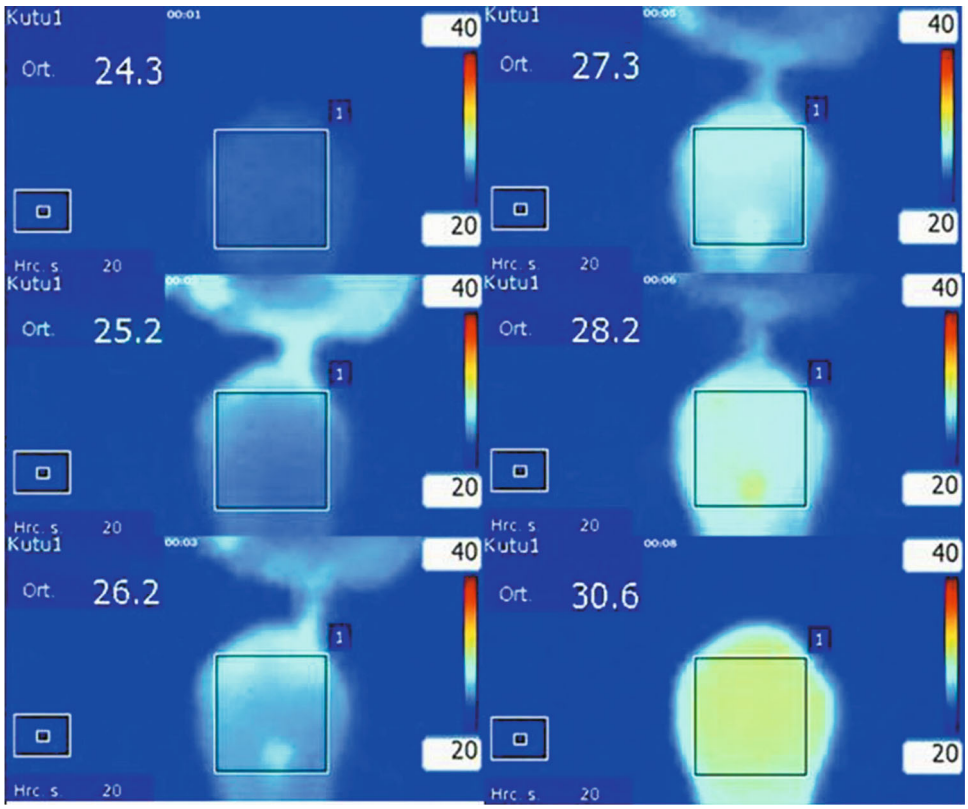

Fig. 5 Thermal images of a sample tooth during clean-up. The temperature rose from 24.3 to 30.6 °C
Abb. 5 Thermoaufnahmen eines Zahns während der Adhäsiventfernung. Temperaturerhöhung von 24,3 auf 30,6 °C

Tab. 2 Comparison of initial and final temperature changes with different clean-up procedures
Tab. 2 Vergleich der initialen und finalen Temperaturveränderungen bei unterschiedlichen Verfahren zur Adhäsiventfernung

Groups	T0		T1		T1-T0		*p*
	Mean	SD	Mean	SD	Mean	SD	
Group I	24.06	2.11	25.60	2.15	1.54	0.53	<0.001
Group II	24.00	1.27	28.50	1.44	4.18	0.96	<0.001
Group III	24.81	1.90	25.14	1.36	0.48	0.90	0.216
Group IV	24.56	1.56	29.71	2.02	5.91	0.89	<0.001

T0 Before adhesive removal, *T1* End of adhesive removal, *SD* standard deviation

using a 12-fluted tungsten carbide bur. Parallel with the smallest temperature rise, the water cooling group displayed the shortest cool down time (11.90 ± 5.3 s; Table 3).

Only 9 samples in Group II and 12 samples in Group IV showed temperature increases ≥5.5 °C. For this reason, comparison of cool down times to critical temperature threshold values (CTC) was performed only between Groups II and IV, which used air cooling in high-speed handpieces (Table 3). Group IV using a 6-fluted TCB exhibited the longest cooling duration to return to the critical threshold value (15.50 ± 4.03 s) followed by Group II using 12-fluted TCB (11.66 ± 2.93 s; Table 3).

Tab. 3 Comparison of temperature difference, time changes, and critical time changes between groups
Tab. 3 Temperaturunterschiede, Zeitveränderungen und kritischen Zeitveränderungen: Vergleiche zwischen den Gruppen

Groups	Group I		Group II		Group III		Group IV		*p*
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
TD	1.54^{a}	0.53	4.18^{b}	0.96	0.48^{c}	0.90	5.91^{d}	0.89	<0.001
CT	41.85^{w}	14.43	51.95^{x}	12.50	11.90^{y}	5.3	71.95^{z}	13.68	<0.001
CTC	–	–	11.66^{α}	2.93	–	–	15.50^{α}	4.03	0.130

TD temperature difference, *CT* cooling time, *CTC* critical cooling time, *SD* standard deviation
Groups with different letters are significantly different from each other

Discussion

The tungsten carbide burs have been reported as the most efficient method for residual adhesive clean-up [6, 15]. Eminkahyalıgil et al. [6] found that high-speed tungsten carbide bur application was the most effective and the least time-consuming method to clean the teeth surfaces, but the authors stated that it was the most hazardous procedure due to harder structure of tungsten carbide burs than the enamel. Van Waes et al. [19] and Zachrisson and Årtun [21] suggested low-speed tungsten carbide bur application which produced the finest scratch pattern with the least enamel loss. On the contrary, Zarrinnia et al. [22] recommended the use of a high-speed tungsten carbide bur (above 200,000 rpm) with a 12-fluted tungsten carbide bur for removal of remnant resin. Retief and Denys [15] recommended the use of a tungsten carbide bur at a high speed with adequate air cooling, while Rouleau et al. [16] and Campbell [3] suggested water cooling instead of air cooling. Because contradictory reports have been presented in the literature, thermal effects of different types of tungsten carbide burs, cooling applications, and handpieces were tested for this study to define an optimum remnant adhesive clean-up procedure from the enamel surface using tungsten carbide burs without causing thermal injury to the pulpal tissues.

Previous studies evaluating the thermal effects of various remnant adhesive clean-up procedures used different types of thermocouple wires for measuring the temperature changes in the pulp chamber [7, 18]. The thermocouple wires can give only data from their contact points with the dentin and accurate placement of the thermocouple tip at the site of maximum temperature rise is questionable. Thermal image recording systems can detect the microscopic temperature changes over time on the complete surface of the pulpal wall, so the maximum heat generated during adhesive removal that can be transferred to the pulpal tissues can be measured more accurately than other thermal measurement methods. Another advantage of thermal imaging is to transfer and to display temperature differences into real-time video images during all clean-up process, so cooling times of the teeth to initial temperature values can also be visualized and measured [5]. The thermal camera was placed on the pulpal side of the samples for our study, and the heat transferred from vestibule side to the pulpal wall was measured. The thermal injury will initially affect the pulpal tissue in direct contact with the pulpal wall, so temperature rise on the pulpal wall surface is of most interest [5]. There are no studies in the literature using thermal cameras to evaluate the temperature changes during remnant adhesive clean-up after bracket debonding.

After the animal study of Zach and Cohen [20], a 5.5 °C temperature rise of the pulpal tissues has been accepted as a threshold value for thermal injury in thermal studies, but using this threshold for evaluating the results of our study 1:1 can be inappropriate. The temperature increase in the pulp area during adhesive clean-up would be less in vivo than in experimental conditions because the blood flow in the pulpal tissues, blood circulation in the surrounding bone, and the periodontal ligament all have cooling effects [5].

The safe tolerance limit of human pulpal tissues to thermal changes during various dental applications is still unknown. There is no human study that defines the lowest temperature rise of the pulpal area that would cause pulpal injury, but there is some experimental evidence in the literature to suggest that temperature rises above 5.5 °C may cause thermal damage to the human pulpal tissues. Jost-Brinkmann et al. [8] used 25 human permanent teeth indicated for extraction for orthodontic reasons to evaluate the effect of thermodebonding of ceramic brackets on the pulpal tissues and found localized damage to the pulp in several teeth where more than one heating cycle was used. Baldissara et al. [2] evaluated the thermal injury clinically and histologically in 12 human teeth which were scheduled for extraction for orthodontic or functional purposes. The intrapulpal temperature rise ranged between 8.9–14.7 °C and the authors stated that postoperative inflammation or necrosis of the pulpal tissue was mainly due to the short-term injury of the dentine, which has direct functional and physiological connection with the pulp [2]. Langeland stated that serious pulp injury can be totally asymptomatic because there is generally a discrepancy between clinical and morphological data, so the absence of clinical symptoms does not always indicate that the pulp is healthy [2, 11]. As there is no data about thermal thresholds of human pulp chamber, it is rational to use a remnant adhesive removal procedure that minimizes possible iatrogenic problems.

Only the 6-fluted TCB with a high-speed handpiece with air cooling group exceeded the critical 5.5 °C threshold value of Zach and Cohen (mean 5.91 ± 0.89 °C) among study groups [20], while 12-fluted TCB application using a high-speed handpiece with air cooling showed a 4.18 ± 0.96 °C temperature rise in the pulpal area. Similarly, Jonke et al. [7] also found that fine burs caused lower pulpal temperature rise during adhesive removal in their study, which evaluated the temperature rise with three types of carbide burs (6-, 12-, 40-fluted) on a high-speed handpiece. The 6-fluted TCB group showed a 9.4 °C temperature rise, and 12-fluted and 40-fluted TCB applications increased pulpal heat 6.5 and 1.2 °C, respectively. The advantage of using fine burs is not only obtaining the low temperature rise, but also to have a more refined and smooth enamel surface due to the greater number of blades with shortened distance [17].

The speed of the handpiece is also an important factor for the thermal injury of the pulp. Use of low-speed handpieces is recommended because they cause minimum damage to the enamel, less uncomfortable vibration, and less pain perception [14, 17]. The 6-fluted TCB application at a low and a high-speed handpiece with air cooling increased the pulpal heat 1.54 ± 0.53 and 5.91 ± 0.89 °C, respectively, so the high-speed handpiece group exceeded the critical 5.5 °C of the threshold value. Uysal et al. [18] compared temperature changes in high and low-speed contra-angle handpieces without water cooling during adhesive clean-up after bracket debonding. The temperature increased 4.27 ± 1.28 °C in the low-speed group and high-speed group exhibited 7.58 ± 1.84 °C temperature rise. The results of all these studies show that using low-speed rotary instruments can cause less or minimal thermal damage to pulpal tissues.

Using cooling techniques, especially water cooling has been reported as the most effective method for limiting the temperature rise of the pulpal area [1, 18]. Uysal et al. [18] reported a 7.58 ± 1.84 °C temperature rise for high-speed contra-angle handpiece without water cooling and a -4.98 ± 2.22 °C temperature decrease with water cooling. The 6-fluted TCB group with a high-speed handpiece that utilized water for cooling showed the least temperature rise among study groups of our study (0.48 ± 0.90 °C). Although air cooling was used, 6-fluted TCB application with a high-speed handpiece exceeded the critical 5.5 °C of the threshold value (5.91 ± 0.89 °C). Atrill et al. [1] found a 24.7 °C of temperature rise during tooth preparation without water cooling and when water cooling was used, the temperature rise was 3.9 °C. In order to minimize the thermal damage during adhesive clean-up, a cooling procedure must be used. If a low-speed handpiece is used, air cooling can be effective for limiting the temperature rise of the pulpal area, but if residual adhesive removal is achieved with a TCB with a high-speed handpiece, water spray is the most efficient cooling method.

Cool down times to initial values (CT) and cool down times to 5.5 °C of critical threshold values of the teeth (CTC) were also calculated. There are no data in the orthodontic literature about cooling of teeth during adhesive removal. The cool down times in the study groups showed results parallel to the temperature change, i.e., when more temperature rise is obtained, CT and CTC also increased. In the air cooling groups, cool down duration to initial temperature values were between nearly 42 and 72 s, and for water cooling group, CT was almost 12 s. Cummings et al. [5] found a 16.2 °C of pulpal wall temperature increase during the removal of ceramic brackets at the end of one heating cycle and showed that the pulpal wall temperature returned to normal within 2–3 min. Thus, a 5 min of cooling period before re-inserting the heating element in the bracket was recommended by the authors [5]. Only samples in 6-fluted and 12-fluted TCB groups with air cooling exceeded the critical 5.5 °C threshold value, and CTC values were 15.50 ± 4.03 s for 6-fluted TCB and 11.66 ± 2.93 s for 12-fluted TCB. Significant temperature increases above 5.5 °C were reported in the literature during both light curing of orthodontic brackets and remnant adhesive removal after bracket debonding [12, 18]. Because the exact thermal tolerance limit of human pulp is still unknown, these results showed that enough time must be given to the teeth to cool down after adhesive clean-up before initiating an orthodontic or a dental procedure like rebonding of the failed brackets or tooth reshaping with high-speed handpieces, especially at mandibular incisors that have thin enamel and dentin. Therefore, it appears sensible to allow the teeth to cool for approximately 20 s to avoid the thermal injury of the pulp after adhesive clean-up.

Conclusions

- Only the 6-fluted TCB group with a high-speed handpiece and air cooling exceeded the critical 5.5 °C threshold value.
- Water cooling is more effective for limiting the temperature rise of the pulp with a high-speed handpiece.
- Fine TCBs and low-speed handpieces are recommended during residual adhesive removal to ensure less thermal damage to the pulpal tissues.
- Nearly 20 s of cool down time should be given to the teeth after adhesive clean-up before initiating another orthodontic or dental application causing temperature increase, like rebonding of failed brackets or reshaping of the tooth with high-speed handpieces.

Compliance with ethical guidelines This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest G. Kurt, N. Gül, Ö. Er, G. Çakmak, E. Bendeş, and V. Aslantaş declare that they have no conflict of interest.

References

1. Attrill DC, Davies RM, King TA, Dickinson MR, Blinkhorn AS (2004) Thermal effects of the Er:YAG laser on a simulated dental pulp: a quantitative evaluation of the effects of a water spray. J Dent 32:35–40
2. Baldissara P, Capatano S, Scotti R (1997) Clinical and histological evaluation of thermal injury thresholds in human teeth: a preliminary study. J Oral Rehabil 24:791–801
3. Campbell PM (1995) Enamel surfaces after orthodontic bracket debonding. Angle Orthod 65:103–110

4. Cardoso LAM, Valdrighi HC, Vedovello Filho M, Correr AB (2014) Effect of adhesive remnant removal on enamel topography after bracket debonding. Dent Press J Orthod 19:105–112
5. Cummings M, Biagioni P, Lamey PJ, Burden DJ (1999) Thermal image analysis of electrothermal debonding of ceramic brackets: an in vitro study. Eur J Orthod 21:111–118
6. Eminkahyagil N, Arman A, Çetinşahin A, Karabulut E (2006) Effect of resin-removal methods on enamel and shear bond strength of rebonded brackets. Angle Orthod 76:314–321
7. Jonke E, Weiland F, Freudenthaler JW, Bantleon HP (2006) Heat generated by residual adhesive removal after debonding of brackets. World J Orthod 7:357–360
8. Jost-Brinkmann PG, Stein H, Miethke RR, Nakata M (1992) Histologic investigation of the human pulp after thermodebonding of metal and ceramic brackets. Am J Orthod Dentofac Orthop 102:410–417
9. Kilic K, Er O, Kilinc HI, Aslan T, Bendes E, Sekerci AE, Aslantas V (2013) Infrared thermographic comparison of temperature increases on the root surface during dowel space preparations using circular versus oval fiber dowel systems. J Prosthodont 22:203–207
10. Kwon SJ, Park YJ, Jun SH, Ahn JS, Lee IB, Cho BH, Son HH, Seo DG (2013) Thermal irritation of teeth during dental treatment procedures. Restor Dent Endo 38:105–112
11. Langeland K (1959) Histologic evaluation of pulp reactions to operative procedures. Oral Surg Oral Med Oral Pathol 12:1235–1248
12. Malkoç S, Uysal T, Üşümez S, Işman E, Baysal A (2010) In-vitro assessment of temperature rise in the pulp during orthodontic bonding. Am J Orthod Dentofac Orthop 137:379–383
13. Mank S, Steineck M, Brauchli L (2011) Influence of various polishing methods on pulp temperature: an in vitro study. J Orofac Orthop 72:348–357
14. Mollica FB, Camargo FP, Zamboni CS, Pereira SMB, Teixeira SC, Junior LN (2008) Pulpal temperature increase with high-speed handpiece, Er: YAG laser and ultrasound tips. J Appl Oral Sci 16:209–213
15. Retief DH, Denys FR (1979) Finishing of enamel surface after debonding of orthodontic attachments. Angle Orthod 49:1–10
16. Rouleau BD Jr, Marshall GW Jr, Cooley RO (1982) Enamel surface evaluations after clinical treatment and removal of orthodontic brackets. Am J Orthod 81:423–426
17. Tonetto MR, Frizzera F, Porto TS, Jordão KF, de Andrade MF, dos Santos RS, Klug RJ, Bandeca MC (2014) Methods for removal of resin remaining after debonding of orthodontic brackets: a literature review. J Dent Res Rev 1:105–117
18. Uysal T, Unverdi Eldeniz A, Usumez S, Usumez A (2005) Thermal changes in the pulp different adhesive clean-up procedures. Angle Orthod 75:220–225
19. Van Waes H, Matter T, Krejci I (1997) Three-dimensional measurement of enamel loss caused by bonding and debonding of orthodontic brackets. Am J Orthod Dentofac Orthop 112:666–669
20. Zach L, Cohen G (1965) Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 19:515–530
21. Zachrisson BU, Årtun J (1979) Enamel surface appearance after various debonding techniques. Am J Orthod 75:121–137
22. Zarrinnia K, Eid NM, Kehoe MJ (1995) The effect of different debonding techniques on the enamel surface: an in vitro qualitative study. Am J Orthod Dentofacial Orthop 108:284–293